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MINIATURE GAIN BLOCK FOR SATELLITE COMMUNICATION TRANSCEIVERS

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ABSTRACT

The development and optimization of a two-stage Ku-band feedback amplifier using miniature lumped element circuits in batch processed form is described. Bondwires are replaced by electroformed interconnects to reduce parasitics and improve reproducibility and reliability. Results on pre-space qualification thermal and radiation tests are presented.

INTRODUCTION

Space-based communications systems need small microwave circuits that are highly integrated and reliable. There are strong incentives for making the circuits as small and light as possible, while maintaining high performance standards. A high degree of reproducibility and low cost is achieved by batch fabrication.

The pioneering work on lumped-element microwave components carried out at RCA Laboratories [1] laid the foundation for the processing and rf characterization of thin-film lumped element circuits, which led to the development of a new technology for miniature hybrid circuits (Quasi-monolithic technology)[2]. This technology is based on batch processing of passive microwave integrated circuits using a mixture of thin film lumped element and distributed components. Active devices in chip form are pretested and subsequently bonded to the circuits. Instead of wire bonding, a newly developed electroformed interconnect system is used that offers very low parasitics and most importantly is highly reproducible; a necessity with increasing frequency.

We developed a general purpose gain building block for small signal amplifiers or limiters designed to suit satellitte communication receivers. The circuits were batch fabricated to achieve the necessary high degree of reproducibility and ultimately low cost.

In this paper we concentrate on the different development steps of a two stage amplifier covering the 11.7 GHz to 12.2 GHz frequency band. Circuit design, fabrication, and pre-space qualification thermal and gamma radiation tests are presented.

DESIGN AND CIRCUIT LAYOUT

The circuit was designed to cover a wider frequency band to guarantee a reproducible performance over the desired band 11.7 GHz to 12.2 GHz. The design uses negative feedback to desensitize the circuit performance to FET-parameter variations. Negative feedback allows for both intra- and inter-batch variations without affecting performance. In addition, the types of elements used in the reactive matching circuitry were carefully chosen, so that the predicted performance would be obtained.

The input and output matching networks use shunt and series transmission line sections. The transmission line sections are electrically short, and therefore, mainly inductive. Such lines can be made to close tolerances. Lumped capacitors, on the contrary, have much wider fabrication tolerances and thus are preferably used for dc blocking and rf decoupling.

The circuit design was analyzed and optimized to determine the amount of negative feedback required to produce the best compromise between different performance parameters. A tolerance analysis was performed to study the circuit sensitivity to component uncertainties caused by fabrication tolerances, modeling approximations, and measurement errors. The analysis estimates the manufacturing yield, where the statistical variables are the substrate material, FET device S-parameters, tuning capacitors, and matching sections. The design was accordingly modified to achieve a high degree of reproducibility within the specified statistical window. The amplifiers were batch fabricated (as shown in Fig.1) using the fabrication process described in [2].

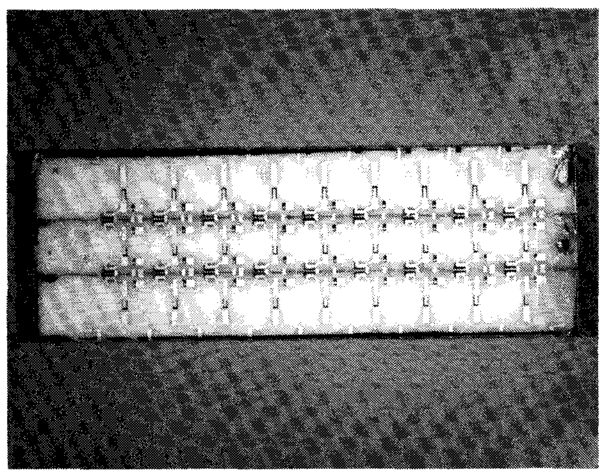

Fig.1 Dual stage amplifiers batch fabricated on a common substrate.

In earlier circuits we used bondwires to bond the FET device to the circuits (see Fig.2). However, wire bonds have considerable parasitic inductance, require highly skilled operators and are not well reproducible. In addition, bonding pads on microwave low noise GaAs FET chips are generally very small (1 to 2 mil^2), and are very difficult to interconnect with the rf circuit. Recently, a new step towards automated assembly of microwave devices has been developed at RCA. The interconnect shown in Fig.3, offers batch processed, highly reproducible interconnect pattern with very low parasitics, built-in insulation by a polyimide ring, and very good bondability due to soft Au-bumps. The FET chip can either be recessed into a hole drilled into the alumina substrate, or it can be flip-chip mounted as shown in Fig.4. The sources of the FET pellet are directly bonded to the septum ground to provide a very low inductance connection.

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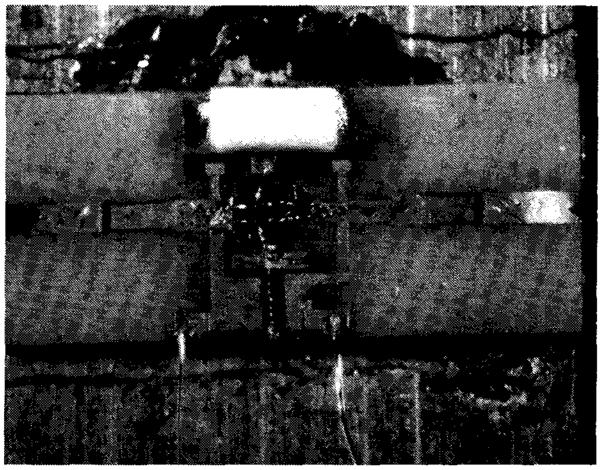

Fig.2 Photograph of a single stage feedback amplifier, the circuit size is 100x80mil and the NE710 FET device is recessed in a 25mil diameter hole and wire bonded to the circuit.

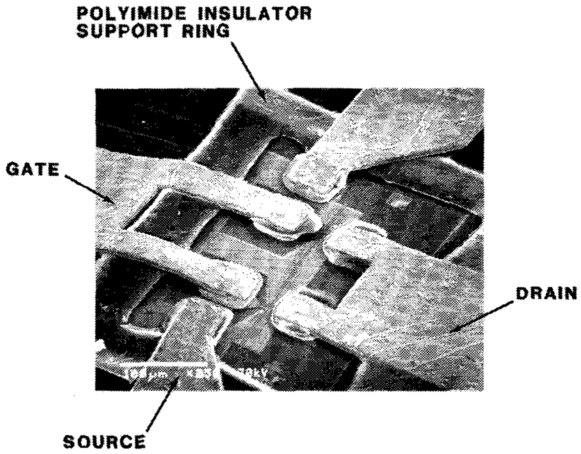

Fig.3 Photograph of low-noise GaAs FET bonded to electroformed interconnect.

MEASURED RESULTS

The measured rf performance of these amplifiers showed a gain of 6.5±.15dB/stage over the frequency range 11.7 GHz to 12.2 GHz. The input-output return loss is better than 20dB within the band (see Fig.5). The noise figure is less than 4dB and the amplifier is capable of delivering over 15dBm at 1dB compression.

Early experiments with the electroformed interconnects demonstrated excellent rf performance. Fig.4 shows a chip conventionally recess-mounted in a ceramic substrate. A comparison of S_{11} between a wire bonded chip and the lead bonded chip is shown in Fig.6. Note the much higher Q of the lead-bonded chip. Similar results were obtained by flip-chip mounting a device after the interconnect had been bonded to the chip. Although the heat dissipated in the chip in this case has to be transfered via the Au leads, the increase in chip temperature is only 10^0 C at typical bias condition of 3V and 10mA.

For space applications it is very important to gain information about the behavior of these amplifiers during exposure to severe radiation environments. The radiation effects on the amplifier, including changes in the dc characteristics of the GaAs FETs, were investigated as a function of gamma radiation dosage. No significant degradation has been observed

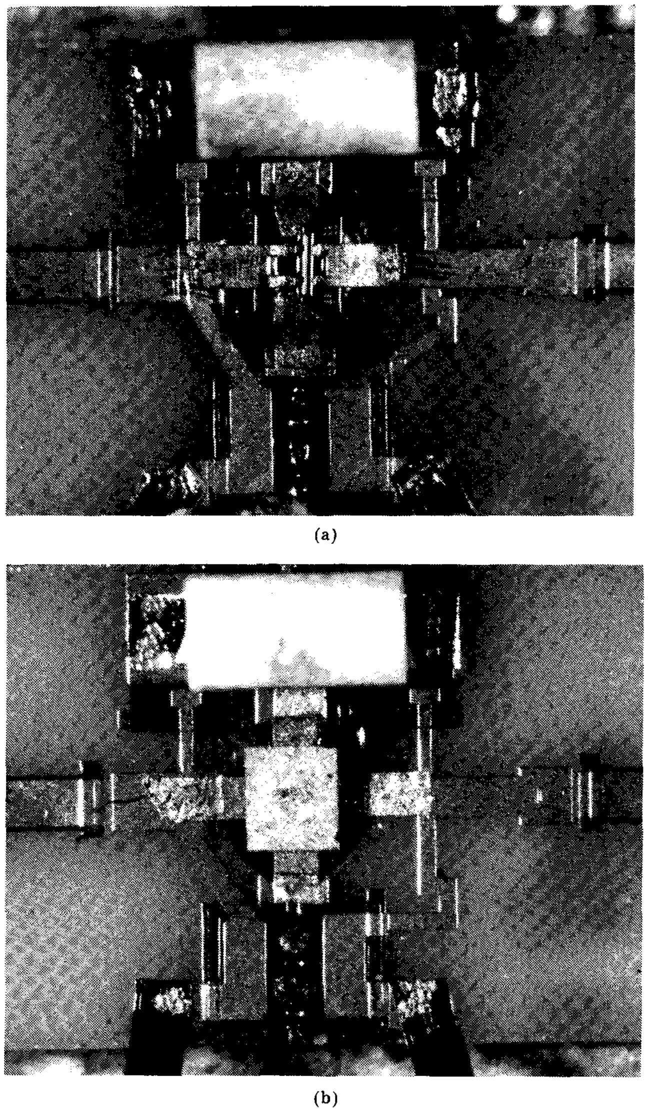

Fig.4 Single stage amplifier with electroformed interconnects
a) NE710 chip mounted recessed in substrate
b) NE710 flip-chip mounted on top of substrate.

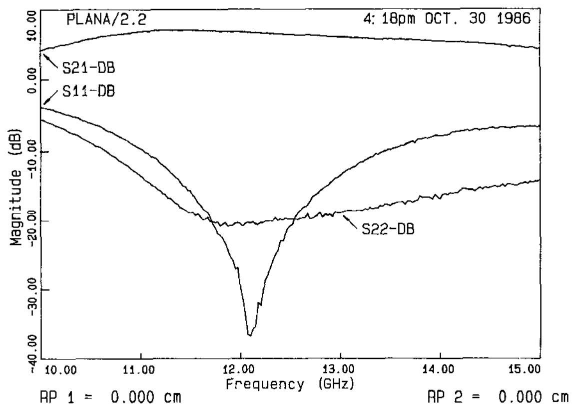

Fig.5 Performance of 11.7-12.2 GHz amplifier which uses an NEC710 chip with electroformed interconnects.

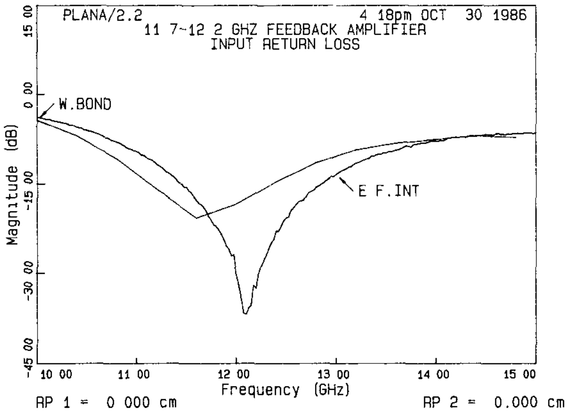

Fig.6 Comparison of input return loss.

for any capacitors or resistors used to fabricate these circuits up to 10M Rad; the equivalent life time radiation dose of a typical satellite. Only a slight variation in the dc and rf performance of these amplifiers were noted. Table 1 shows the rf and dc performance before and after radiation.

The amplifiers also passed temperature cycling tests, from -50° C to +125° C. The amplifiers were enclosed in a hermetically sealed environment and the temperature was varied between the two limits five times with a half hour pause at each temperature. Again, only slight variations within measurement accuracy were noticed for the rf circuits. Fig.7 shows the performance before and after the temperature cycling.

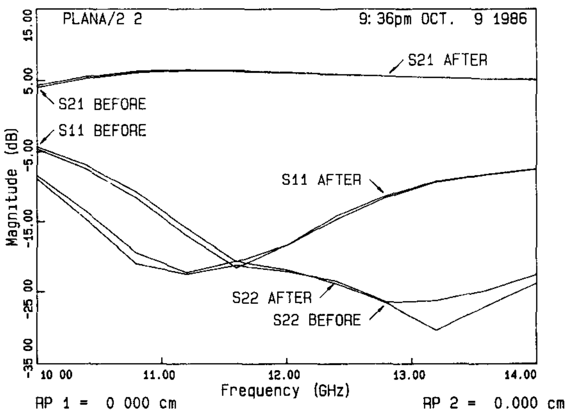

Fig.7 Performance of the amplifier before and after temperature cycling.

CONCLUSIONS

The process technology for batch fabricated miniature hybrid circuits has considerably advanced in the past few years. The introduction of precision interconnects in addition to lowering the parasitics generally contributes to better reproducibility and reliability. The developed two-stage feedback amplifier covering the 11.7 to 12.2 GHz range has 13 dB gain, a 4-dB noise figure and input and output return losses of 20 dB. Preliminary space qualification tests show these circuits to be rugged and well suited for satellite communication applications.

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Pin	6 dBm				0 dBm				-5 dBm				-10dBm			
RAD	Vg	Ig	Ids	Pout	Vg	Ig	Ids	Pout	Vg	Ig	Ids	Pout	Vg	Ig	Ids	Pout
-	V	uA	mA	dbm	V	uA	mA	dbm	V	uA	mA	dbm	V	uA	mA	dbm
PRAD	-0.58	3.4	20.0	11 08	-0.6	1.2	13.0	5.43	-0.61	0.8	11.2	0.61	-0 61	0 8	10.7	-4 27
1M	-0.58	3.4	21.0	11.62	-0.61	1.4	13 4	5.89	-0.61	1.0	11.4	1 04	-0 61	0.8	10 7	-3 90
3M	-0 58	4.2	21 0	11.80	-0.61	1.6	13.4	5.88	-0 61	1.1	11 3	1.02	-0.61	1 0	10 6	-3 95
6M	-0.58	4.2	21.0	11.80	-0.60	1.8	13.4	5.87	-0 61	1.1	11 3	1.00	-0 61	1 2	10 6	-3 98
10M	-0 60	4.2	20 1	11 03	-0.61	1.5	12.1	5 43	-0.61	1 0	10.1	0 70	-0 61	1 0	9.5	-4.24

UNIT 1

Pin	6 dBm				0 dBm				-5 dBm				-10dBm			
RAD	Vg	Ig	Ids	Pout	Vg	Ig	Ids	Pout	Vg	Ig	Ids	Pout	Vg	Ig	Ids	Pout
-	V	uA	mA	dbm	V	uA	mA	dbm	V	uA	mA	dbm	V	uA	mA	dbm
PRAD	-0 61	2.4	21 0	10.36	-0.63	1.2	13.1	5.05	-0.63	1 0	11 1	0.43	-0.63	1.0	10 4	-4 46
1M	-0.61	2.4	21 0	10 40	-0 62	1.2	12.9	5.05	-0.62	1 0	11 0	0 16	-0.63	1 0	10.4	-4.55
3M	-0.61	2.4	21.1	10.65	-0.61	1.2	13.2	5.20	-0.62	1 0	11 0	0.58	-0 63	1 0	10 4	-4.34
6M	-0 61	2.6	21.8	10.95	-0.63	1 4	13.2	5.22	-0 63	1.0	11.0	0.55	-0.63	1 0	10.2	-4.34
10M	-0 61	2.8	21.2	10.52	-0.63	1.2	12.5	4.87	-0.63	0.9	10 4	0.18	-0.63	0.8	9.8	-4 60

UNIT 2

TABLE 1

REFERENCES

[1] M. Caulton, et al., "Status of Lumped Elements in Microwave Integrated Circuits, Present and Future," IEEE Trans. on Microwave Theory and Tech., p. 588, July 1971.

[2] E. Belohoubek, "Miniature Microwave Hybrid Circuits-Alternative to Monolithic Circuits, "RCA Review 46, pp. 464-483, December 1985.